The Brigalow Catchment Study: Clearing brigalow *(Acacia harpophylla)* for cropping or pasture increases runoff in central Queensland, Australia

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1. Abstract

The Brigalow Catchment Study (BCS) was established to determine the impact on hydrology when brigalow land is cleared for cropping or pasture. The paired catchment study was commenced in 1965 using catchments of approximately 15 ha, with natural vegetation dominated by brigalow scrub (*Acacia harpophylla*). Three contiguous catchments were selected near Theodore in central Queensland, Australia, to represent the extensive brigalow bioregion of central and southern Queensland and northern New South Wales (approximately 40 million hectares). The hydrology of the three catchments was characterized during a 17-year calibration period (1965–81). The catchments were considered hydrologically similar, with sufficient data available for an empirical comparison between catchments. In 1982, two of the three catchments were cleared, with one developed for cropping and the other sown to improved pasture. The third catchment was used as an uncleared control. Hydrologic characteristics were then compared for the following 21 years. In their virgin state, the catchments behaved similarly, with average annual runoff being 5% of annual rainfall. Once cleared, total runoff from the cropping catchment increased to 11% of annual rainfall and total runoff from the pasture catchment increased to 9% of annual rainfall, however timing of the individual runoff events varied between land uses. In order to confirm that changes in hydrology were a function of land use and not just seasonal variability or sampling error, a number of analytic techniques were used: a simple comparison of both observed and calibrated runoff totals, and comparison of predicted and observed runoff using a water balance modelling approach.

2. Introduction

The brigalow bioregions of Queensland and New South Wales occupy 36.7 million hectares, stretching from Dubbo in the south to Townsville in the north (Department of Environment and Heritage 2006). Since European settlement, 58% of this bioregion has been cleared (National Land and Water Resources Audit 2002). In 1962, the Brigalow Land Development Fitzroy Basin Scheme commenced, resulting in the clearing of 4.5 million hectares for cropping and grazing (Land Administration Commission 1968). This clearing represents 21% of all clearing in the brigalow bioregions, and represents 32% of the Fitzroy Basin Catchment area. In order to quantify the effect of land clearing on hydrologic change, the Brigalow Catchment Study commenced in 1965.

A number of methods for investigating hydrologic change associated with land clearing and development are described in the literature, with results being critically dependent on methodology (Siriwardena *et al*. 2006). The simplest approach is similar to that of Adamson (1976), where two similar catchments are selected and subjected to different treatments without calibration. The limitation to this approach is that differences in catchment runoff are solely attributed to changes in management, and any inherent differences in the catchments are ignored. Calibrated catchments such as those used in this study seek to avoid this limitation, however variable climate sequences can still greatly alter treatment effects (Fernandez and Garbrecht 1994). Due to the complex processes associated with runoff generation, simply comparing rainfall and runoff before and after clearing is inadequate to detect and quantify change (Siriwardena *et al*. 2006). An alternative approach, applied in both Australia (Siriwardena *et al*. 2006) and Africa (Lørup *et al*. 1998), is to use hydrological modelling. Daily rainfall-runoff models are calibrated to observed pre-clearing runoff, and observed post-clearing runoff is then compared to the simulated pre-clearing runoff in the same period.

Several analytical methodologies were applied to the 40 years of rainfall and runoff data collected from the Brigalow Catchment Study in order to confidently provide benchmark information on hydrologic changes associated with clearing of brigalow lands for cropping or pasture.

3. Methods

The BCS is located at 24.81° S, 149.80° E using the Geocentric Datum of Australia, in the Dawson sub catchment of the Fitzroy basin, central Queensland, Australia. The region has a semi-arid, subtropical climate with wet summers and low winter rainfall (70% of the annual average calendar rainfall of 720 mm falls between

October and March). Rainfall is highly variable, ranging from 11 mm or less in any month, to 165 mm in one day. Annual evaporation is 2133 mm, and average evaporation is at least twice the average rainfall in all months.

The BCS is a paired catchment study consisting of three catchments. The study has been divided into three distinct experimental stages: I, II and III (Table 1). The areas of the catchments are 16.8 ha (catchment 1 – C1), 11.7 ha (catchment 2 – C2) and 12.7 ha (catchment 3 – C3). Mean slope of the catchments is 2.5%. Soil types in the catchments comprise associations of Black and Grey Vertosols, some with gilgais, Black and Grey Dermosols, and Black and Brown Sodosols (Isbell 1996). In their native state, the catchment sites were composed of three major vegetation communities, identified by their most common canopy species; brigalow (*Acacia harpophylla*), brigalow – belah (*Casuarina cristata*) and brigalow – Dawson Gum (*Eucalyptus cambageana*). Understoreys of all major communities are characterized by *Geijera* sp. either exclusively, or in association with *Eremophila* sp. or *Myoporum* sp. The catchments were good quality agricultural land, all equally suitable for cropping or grazing. Each catchment was instrumented to measure runoff using a 1.2 m steel HL flume with concrete approach box**.** Water height through the flumes was recorded using mechanical float recorders. Rainfall was recorded adjacent to each flume and at the head of the catchments. Comprehensive climate and site descriptions along with experimental methodologies are given in Cowie *et al.* (2007), Radford *et al*. (2007) and Thornton *et al.* (2007).

Table 1 The land use history of the three catchments of the Brigalow Catchment Study.

	Land use by experimental stage		
Catchment	Stage I (Jan 1965-Mar 1982)	Stage II (Mar 1982-Sep 1984)	Stage III (Sep 1984-Dec 2004)
1	Virgin brigalow scrub	Virgin brigalow scrub	Virgin brigalow scrub
2	Virgin brigalow scrub	Development	Cropping
3	Virgin brigalow scrub	Development	Improved pasture

During Stage I, the catchments in their virgin state were monitored by collecting rainfall and runoff data. The aim of this 17-year calibration phase was to identify the inherent differences in catchment runoff characteristics to ensure that any change in hydrology could be attributed to change in land use. Data collected during calibration can be used to describe differences in catchment responses to a range of weather sequences. This was achieved by regressing event runoff from C2 and C3 against C1 (the reference catchment). A calibration acts as a reference point for a catchment after it is cleared, as well as facilitating a comparison across catchments.

Stage II commenced in March 1982, when the vegetation in C2 and C3 was cleared by bulldozer and chain. The fallen timber was burnt *in situ* in October 1982. This was a traditional method of clearing brigalow lands. In C2, residual unburnt timber was raked to lines on the contour and burnt. Narrow-based contour banks, a recommended soil conservation management practice at the time, were constructed at 1.5 m vertical spacing. A grassed waterway was established to carry runoff water from the contour channels to a sediment settling pond in front of each flume. In C3, unburnt timber was left in place, and in November 1982 the catchment was sown to improved pasture by distributing buffel grass seed (*Cenchrus ciliaris* cv. Biloela) on the soil surface.

Stage III commenced in 1984. In C2, the first crop sown was sorghum (September 1984), followed by annual wheat for nine years. During this period fallows were managed using mechanical tillage (disc and chisel ploughs), which resulted in significant soil disturbance and low soil cover. In 1992 a minimum tillage philosophy was introduced and in 1995 opportunity cropping (sorghum and wheat) commenced with summer or winter crops planted whenever soil moisture level was adequate.

In C3, the buffel grass pasture established well with >5 plants/m^2 and 96% groundcover achieved before grazing commenced in December 1983. Stocking rate was 0.29-0.71 head/ha (each beast typically 0.8 adult equivalent), adjusted to maintain pasture dry matter levels >1000 kg/ha without feed supplementation.

Given the natural variability in catchment behaviour and weather, multiple lines of evidence were used to explore hydrologic responses to land use change. Initial analysis compared measured total runoff between catchments before and after clearing, and attributed relative changes in runoff to land use change. Analysis of variance was used to determine if the changes were statistically significant. A limitation to this approach is that changes may simply reflect differences in rainfall between the two periods. This was quantified using C1 as a reference. The regression equations derived in Stage I (presented in results as equations 1 and 2) were applied to post-clearing data to estimate runoff from C2 and C3, had they remained undisturbed. Hydrologic change was defined as the difference between the runoff measured in C2 and C3 after clearing and the runoff estimated by equations 1 and 2. A daily rainfall-runoff model, HowLeaky?, V2.15 (McClymont et al.2006) based on the PERFECT model (Littleboy et al. 1989), was also used to examine the impact of land use change on runoff and soil water. By modelling the pre and post-clearing records of C2 and C3 for the overall trial period, the effect of land use on runoff and soil water can be determined irrespective of inherent catchment differences and climatic sequences.

4. Results

During Stage I and in their natural condition dominated by brigalow vegetation, average annual runoff across the three catchments was 34mm (approximately 5% of annual rainfall) (Fig. 1). Catchments 1 and 2 averaged 2 runoff events per year, while C3 had 5 runoff events per year but the lowest total runoff. The extra runoff events in C3 ranged from 0.01mm to 1.23 mm, with 97% of these events producing less than 1 mm of runoff. Excluding these events from C3, the three catchments had the same number of events per year and a strongly seasonal monthly distribution of runoff reflecting the monthly distribution of rainfall. Analysis of variance of log-transformed annual and monthly runoff data showed no significant difference ($P > 0.05$) in average annual runoff between the three uncleared catchments.

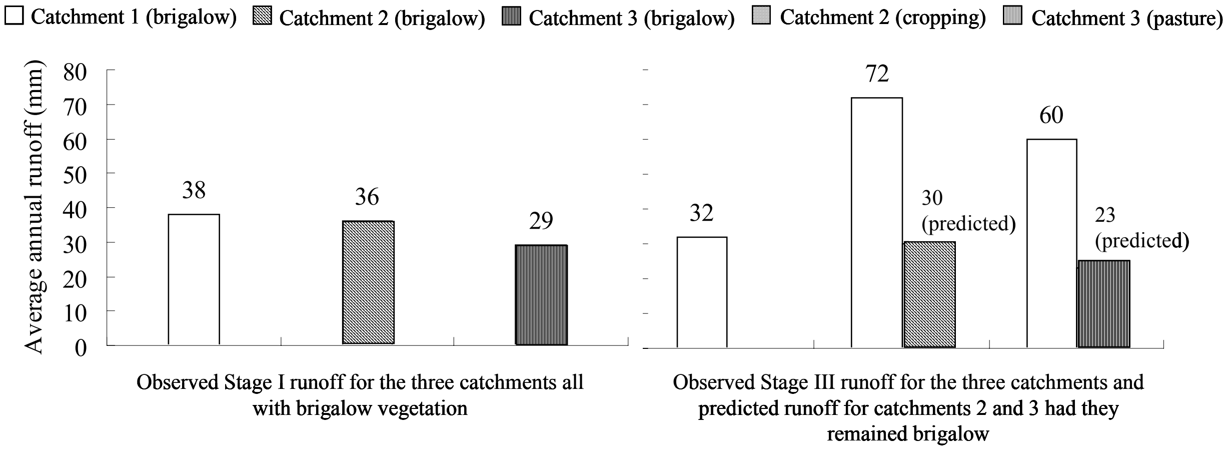

Figure 1 Observed and predicted runoff from the three catchments during the 17-year calibration,(Stage I) and the 20-year land use comparison (Stage III). Predicted runoff from catchments 2 and 3 had they remained uncleared is shown for Stage III. All data has been rounded to zero decimal places.

During Stage III, average annual runoff was 32 mm from C1 (brigalow scrub), 72 mm from C2 (cropping) and 60 mm from C3 (pasture) (Fig. 1) or.5, 11 and 9 % of rainfall, respectively. Catchment 1 continued to average 2 runoff events per year but C2 and C3 had 4 runoff events per year. Runoff from C1 continued to reflect the monthly distribution of rainfall. Runoff from the developed catchments was also seasonal and equalled or exceeded the frequency of runoff from C1 in all months. From mid winter until the end of spring, C3 yielded the highest runoff. Throughout summer C2 yielded the highest runoff. March and April yielded similar runoff from C2 and C3 while May and June runoff was higher from C2. Analysis of variance of log-transformed annual and monthly runoff shows both C2 and C3 > C1 ($P < 0.05$) but C2 not significantly different from C3.

In Stage III, average annual runoff from C2 and C3 was 40 and 28 mm greater, respectively, than C1 (Fig. 1). The brigalow scrub catchment showed no significant differences in average annual or monthly runoff between Stages I and III.

The following equations describe the relationships of runoff between C2 and C3 relative to C1 during Stage I.

$$\text{C2 runoff (mm)} = \text{C1 runoff (mm)} \times 0.9539 \quad (\text{Adjusted } R^2 = 0.95, n = 37) \qquad \text{Equation 1}$$

$$\text{C3 runoff (mm)} = \text{C1 runoff (mm)} \times 0.7176 \quad (\text{Adjusted } R^2 = 0.887, n = 40) \qquad \text{Equation 2}$$

The intercepts of each regression equation were not significantly different from zero ($P > 0.05$) but slopes were significantly different from 1 ($P < 0.001$).

The regression equations (Eqns. 1 and 2) were used to provide estimates of runoff from C2 and C3 during Stage III, had they not been cleared (Fig. 1). Changes in catchment hydrology were then determined from the difference between measured and calculated runoff for the virgin condition. The estimated increases in annual average runoff were 42 mm in C2 and 38 mm in C3. These increases were statistically significant ($P <$ 0.05).

The HowLeaky? model was calibrated to predict daily runoff from each catchment under brigalow scrub and runoff from C2 and C3 with the new land uses of cropping and pasture. Annual average runoff increased by 38 mm in C2 and 21 mm in C3 when converted from brigalow to cropping and pasture, respectively. Soil water predictions showed that during Stage I, there was no significant difference in total available soil water on a daily, monthly or yearly basis across the three catchments ($P < 0.05$). During Stage III the overall trend was for the new land uses to have significantly greater average monthly soil water than the original land use of brigalow. In the cropping catchment, fallow months and at least the first month of growth of both sorghum and wheat had significantly higher average soil water than brigalow ($P < 0.05$). Buffel grass pasture maintained significantly higher average soil water than brigalow ($P < 0.05$) in all months.

5. Discussion

Comparisons of observed data, calibrated catchment data and modelled data support the conclusion that runoff has increased in both frequency and volume with the clearing of native brigalow land for cropping or grazing. The seasonal distribution of the runoff also changed, and differed according to the new system of land use. Hydrological modelling suggests that the key drivers of these changes are primarily changes in water use patterns. For example, buffel grass pasture is active in the summer, and dormant in the winter. Winter crops rely on water stored in the soil over summer fallows, albeit inefficiently, to sustain crop growth in the typically dry winter growing periods. Summer crops similarly rely on stored soil water, although their short growing season of 100-140 days coincides more with the rainfall pattern. Both annual cropping and improved pasture had significant periods of the year without transpiring plants to extract water. We suspect this change in water use pattern is the dominant mechanism responsible for hydrologic change.

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